

Oxidation of Mercury Across SCR Catalysts in Coal-Fired Power Plants Burning Low Rank Fuels

Quarterly Progress Report

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Abstract

This is the third Quarterly Technical Report for DOE Cooperative Agreement No: DE-FC26-03NT41728. The objective of this program is to measure the oxidation of mercury in flue gas across SCR catalyst in a coal-fired power plant burning low rank fuels using a slipstream reactor containing multiple commercial catalysts in parallel. The Electric Power Research Institute (EPRI) and Argillon GmbH are providing co-funding for this program. This program contains multiple tasks and good progress is being made on all fronts. During this quarter, the second set of mercury measurements was made when the catalysts had been exposed to flue gas for about 2,000 hours. There was good agreement between the Ontario Hydro measurements and the SCEM measurements. Carbon trap measurements of total mercury agreed fairly well with the SCEM. There did appear to be some loss of mercury in the sampling system toward the end of the sampling campaign. NO_x reductions across the catalysts ranged from 60% to 88%. Loss of total mercury across the commercial catalysts was not observed, as it had been in the March/April test series. It is not clear whether this was due to aging of the catalyst or to changes in the sampling system made between March/April and August. In the presence of ammonia, the blank monolith showed no oxidation. Two of the commercial catalysts showed mercury oxidation that was comparable to that in the March/April series. The other three commercial catalysts showed a decrease in mercury oxidation relative to the March/April series. Oxidation of mercury increased without ammonia present. Transient experiments showed that when ammonia was turned on, mercury appeared to desorb from the catalyst, suggesting displacement of adsorbed mercury by the ammonia.

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Executive Summary

This project received funding from the Department of Energy under Cooperative Agreement No: DE-FC26-03NT41728. The Electric Power Research Institute (EPRI) and Argillon GmbH are providing co-funding for this program. This project has a period of performance that started February 19, 2003 and continues through September 30, 2004.

Under a separate program (cooperative agreement DE-FC26-00NT40753), Reaction Engineering International (REI) has been funded by the Department of Energy to carry out research and development on NO_x control options for coal-fired utility boilers. The objective of one of the tasks in the NO_x-control program is to evaluate and model SCR catalyst deactivation. REI will be responsible for six-month testing of multiple commercial catalysts simultaneously in a power plant slipstream reactor. This multi-catalyst reactor provides an ideal test bed for advancing the state of knowledge regarding mercury oxidation by SCR catalysts, with a focus on low rank fuels.

In this program, REI is using the multi-catalyst slipstream reactor to determine oxidation of mercury across six separate SCR catalysts at AEP's Rockport Unit 1. During the six-month testing under the existing NO_x-control program, two weeklong sampling campaigns for mercury speciation will be carried out: at the beginning of the six-month period and at an intermediate point. URS will conduct the one-week campaigns to measure gaseous mercury speciation at the inlet and at the outlet of each catalyst chamber.

The specific project tasks are:

- Task 1 Test Preparation
- Task 2 Test Plan
- Task 3 Field Measurements of Mercury Speciation
- Task 4 Data Analysis and Validation
- Task 5 Management and Reporting

During the last three months, our accomplishments included the following:

- A second set of mercury measurements was made in August when the catalysts had been exposed to flue gas for about 2,000 hours.
- The coal composition for the August test series was similar to that from the March/April test series.
- There was good agreement between the Ontario Hydro measurements and the SCEM measurements. Carbon trap measurements of total mercury agreed fairly well with the SCEM. There did appear to be some loss of mercury in the sampling system toward the end of the sampling campaign.
- Relatively little mercury or chlorine was observed in the ash collected from the economizer and the ESP hoppers. Gas-phase halide species were measured using an impinger method. These showed that only about 10% of the chlorine in the coal was present in the gas phase.
- NO_x reductions across the catalysts ranged from 60% to 88% and were strongly dependent on the temperature in the catalyst chamber.

- Loss of total mercury across the commercial catalysts was not observed, as it had been in the March/April test series. It is not clear whether this was due to aging of the catalyst or to changes in the sampling system made between March/April and August.
- In the presence of ammonia, the blank monolith showed no oxidation. Two of the catalysts showed mercury oxidation that was comparable to that in the March/April series. The other three commercial catalysts showed a decrease in mercury oxidation relative to the March/April series.
- Oxidation of mercury increased without ammonia present. Transient experiments showed that when ammonia was turned on, mercury appeared to desorb from the catalyst, suggesting displacement of adsorbed mercury by the ammonia.

Experimental Methods

Within this section we present in order, brief discussions on the different tasks that are contained within this program. For simplicity, the discussion items are presented in the order of the Tasks as outlined in our original proposal.

Task 1 – Test Preparation

Site Description

The Rockport plant consists of two 1300 MW_e B&W opposed wall-fired boilers. These are supercritical boilers that burn a blend of bituminous and subbituminous coals. The average mix is 87% Powder River Basin sub-bituminous and 13% bituminous coal. 100% PRB is burned during off-peak periods and on weekends when the unit is not generally required to operate at full load.

Slipstream Reactor Description

The slipstream reactor designed to test the deactivation of SCR catalysts in the field is operational and collecting data at the AEP Rockport plant. The reactor contains six SCR catalysts in parallel and is designed to withdraw a flue gas sample at the exit of the economizer. The reactor contains five commercial catalysts, both plate and honeycomb type, and one blank ceramic monolith. The commercial honeycomb catalysts have approximately a 7 mm pitch. The blank monolith has a slightly smaller pitch of 6.4 mm. Details of the catalysts' physical properties are given in Table 1. The six catalysts, four monolith and two plate, are configured as shown in Figure 1.

Table 1. Catalyst Properties

Chamber:	1 (Blank)	2	3	4	5	6
Catalyst type:	Monolith	Monolith	Plate	Plate	Monolith	Monolith
Chamber porosity:	58.7%	75.4%	83.4%	85.1%	70.0%	67.6%
Length of catalyst in chamber (inch):	24.4	21.6	43.0	39.5	19.3	19.8
Area per chamber (ft ²):	0.028	0.028	0.128	0.144	0.031	0.030
Number of sub-chambers:	4	4	1	1	4	4
Geometric surface area (ft ² /ft ³):	271.0	153.7	106.1	106.1	149.3	138.0
Volume of catalyst block (ft ³):	0.226	0.200	0.458	0.475	0.202	0.198

Anhydrous ammonia is injected into the flue gas stream near the entrance to the reactor, and blended with a static mixer. The molar ratio of NH₃/NO_x was set in excess of 1 in order to ensure that NO_x destruction was not limited by stoichiometry and to give margin for swings in NO_x levels.

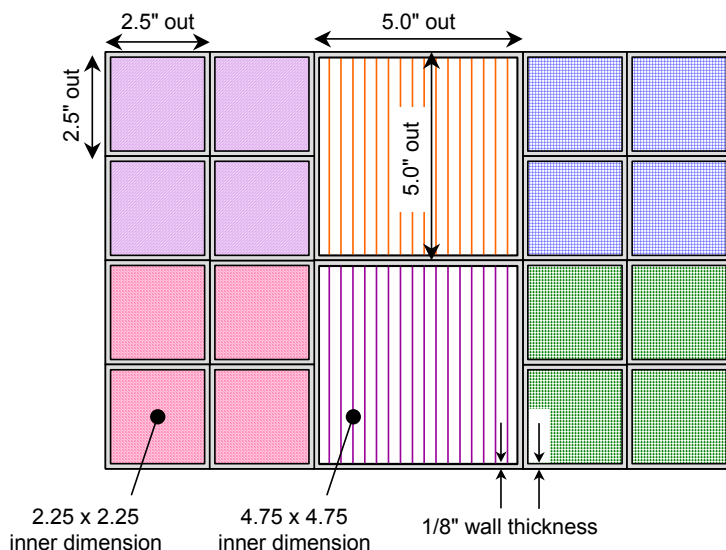


Figure 1. Arrangement of catalysts (plan view)

The SCR slipstream reactor was installed in the flue gas duct downstream of the economizer and upstream of the air preheater on Unit 1. Figure 2 is a schematic of the slipstream SCR reactor as installed at Rockport. A sampling probe was inserted through an existing port in the duct wall. The probe extends approximately three feet into the duct and has a 2-ft long slot, oriented 90° from the direction of flow in the duct. An isolation valve was placed on the inlet line just outside the duct wall. This valve is coupled to the control system, and closes automatically if the flue gas becomes too cold in order to prevent condensation in the catalyst units. The reactor exhaust line is connected to the horizontal duct downstream of the air preheater. As shown in Figure 2, the slipstream reactor is fitted with a 3-inch port for Ontario Hydro measurements, one SCR inlet heated sample line and an outlet heated sample line for each of the six catalyst chambers. Each one of the sample lines feeds into a heated chamber, housing selector valves in a unit called the sequencer. With this arrangement any sampling sequence can be performed using REI's custom-made software.

The system has seven sampling ports, one before the catalyst chambers and one after each of the six catalyst sections. The ports themselves consist of thin stainless steel tubes that enter the channel and bend downward, in line with gas flow. There are sintered metal filters at the point where the individual samples are withdrawn; these can be blown back with compressed air. The inlet sample has a 30-foot heated line (upstream of the sample conditioning unit), 1/4" SS; the six outlet samples have 10-ft heated lines, 1/4" SS. The sample lines are heated to about 250°F.

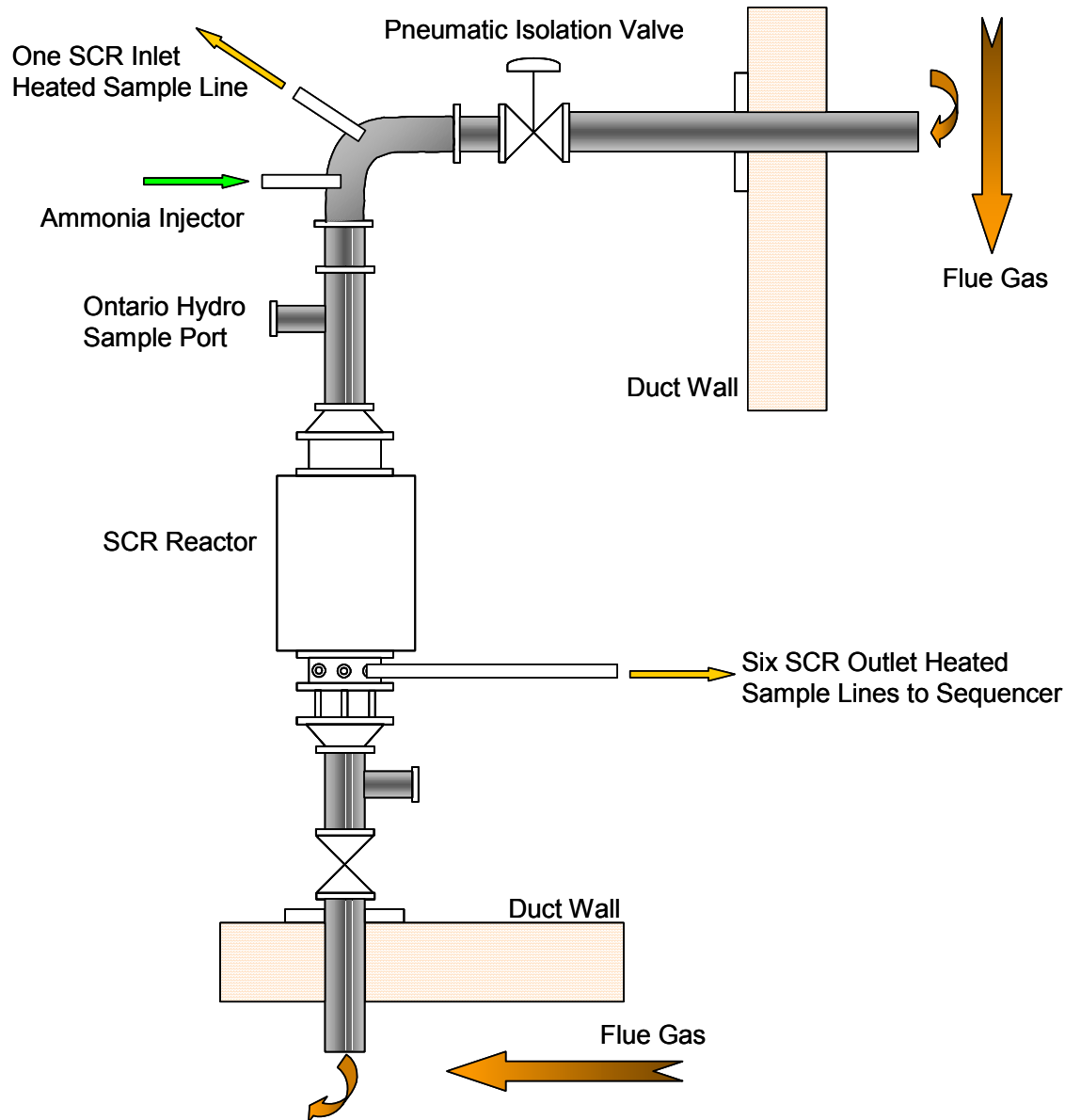


Figure 2. SCR Slipstream Reactor

Task 3 - Field Measurements of Mercury Speciation

The second test series was begun at the beginning of August; data were taken between August 7 and August 16, 2003. The test crew from URS used a semi-continuous mercury emissions monitor (SCEM) to provide near real-time feedback during catalyst evaluations. To minimize fluctuations in mercury in the flue gas, the plant was run at constant load throughout the mercury tests.

During the tests, the temperature in the boiler duct was approximately 730-745°F. Temperature in the catalyst chambers was controlled to 600°F, based on thermocouples located on the outside of the chambers. Stable flow and temperature conditions were generally achieved. Table 2 shows a summary of the test conditions and samples taken.

Table 2. Measurements and samples collected during second test series.

Date	Measurements at Reactor	Sample	Disposition	Analyses
8/7/2003	SCEM: Total Hg at inlet and through Chamber 1 (Blank) SCEM: Inlet Elemental Hg Two out of three Ontario Hydro measurements	Coal: Mills 1&2, 6&7 Fly Ash 3&4	composite	Ult/prox, Hg, Cl LOI, Hg, Cl
8/8/2003	SCEM: Total Hg at inlet One out of three Ontario Hydro measurements Gas-phase halide measurement	Coal: Mills 1&2, 6&7 Fly Ash 3&4	composite hold for now	Ult/prox, Hg, Cl
8/10/2003		Coal: Mills 1&2, 6&7 Fly Ash 3&4	composite hold for now	Ult/prox, Hg, Cl
8/11/2003	SCEM: Total Hg at inlet and outlet of chambers	Coal: Mills 1&2, 6&7 Fly Ash 3&4 Economizer Ash	composite	Ult/prox, Hg, Cl LOI, Hg, Cl LOI, Hg, Cl
8/12/2003	SCEM: Elemental Hg at inlet and outlet of chambers SCEM: Total Hg at inlet	Coal: Mills 1&2, 6&7 Fly Ash 3&4	composite hold for now	Ult/prox, Hg, Cl
8/13/2003	SCEM: Elemental Hg at inlet and outlet of chambers SCEM: Total Hg at inlet	Coal: Mills 1&2, 6&7 Fly Ash 3&4	composite hold for now	Ult/prox, Hg, Cl
8/15/2003	SCEM: Elemental Hg at inlet and outlet of chambers, transient SCEM: Total Hg at inlet	Coal: Mills 1&2, 6&7 Fly Ash 3&4 Economizer Ash	composite	Ult/prox, Hg, Cl LOI, Hg, Cl LOI, Hg, Cl
8/16/2003	SCEM: Elemental Hg at inlet and outlet of chambers, transient SCEM: Total Hg at inlet	Coal: Mills 1&2, 6&7 Fly Ash 3&4	composite hold for now	Ult/prox, Hg, Cl

Coal and ash samples were analyzed by Microbeam Technologies, Inc. (Grand Forks, ND). During the testing on August 7 and 8 both the Ontario Hydro and the SCEM were run simultaneously. The Ontario Hydro sample was taken through the three-inch port upstream of the catalyst chambers indicated in Figure 2. SCEM measurements were made through the individual sample lines, as discussed below. Carbon trap measurements and gaseous halide measurements were made at the SCEM sampling point, too. The gaseous halide measurements were made using impingers designed to separate HCl/HF from Cl_2/F_2 . Analysis of the Ontario Hydro filters and impinger solutions, carbon traps, and halide impinger solutions was carried out by URS.

During the first test series, the sample gases were routed through the sample conditioning and switching unit: seven lines come in from the reactor and one line goes out either to the NO_x/O_2 analyzer or to the mercury SCEM. The switching valves are in a heated box, heated to 175°F . There is blowback air for these valves. Problems were encountered with plugging of ash on the sintered metal filters; the sample lines had to be blown back before each sample.

There was concern after the first test series that the heated switching valve box was too cold and this might result in loss of oxidized mercury, which could explain the apparent loss of total mercury across the catalysts observed in the first test series. The temperature of the heated switching box was turned up, but this caused one of the components to fail. Even after the manufacturer repaired the switching box, ash plugging in the switching box remained a problem. Therefore, the sample lines were individually and manually connected to URS's inertial separation probe for most of the second test series. This is a heated stainless steel probe that has taps to withdraw small sample flows. Gas passing through the sample taps first passes through a sintered metal tube, providing another stage of filtering. Using the inertial separation probe reduced the ash pluggage, but increased the sample time because the sample lines had to be manually disconnected, blown out with air and then reconnected for each sample.

During the second test series, there was difficulty in getting sufficient power to the heaters around the catalyst chambers. Temperatures in the chambers were somewhat lower than in the first test series. While this has an impact on NO_x activity, it is not expected to have a strong impact on mercury oxidation, based on work reported in the literature.¹

Results and Discussion

Task 3 - Field Measurements of Mercury Speciation

Coal and Ash Data

Coal samples were obtained at the outlet of mills 1 and 2, and mills 6 and 7. The samples were composited; ultimate and proximate analyses were carried out by Microbeam Technologies, as well as measurement of Hg and Cl. The Hg and Cl measurements were made at the University of North Dakota Energy & Environmental Center (EERC). Table 3 presents the coal data.

The coal blend is nominally 87% subbituminous (from the Powder River Basin or PRB) and 13% bituminous. The heating value of the coal is commensurate with the blend, as is the coal chlorine content. The mercury content of the coal is equivalent to 4-6 $\mu\text{g}/\text{nm}^3$ of mercury, if all the mercury were in the flue gas at 5% O_2 .

Table 3. Coal Data

Date	8/7/2003	8/8/2003	8/10/2003	8/11/2003	8/12/2003	8/13/2003	8/15/2003	8/16/2003
(As Received):								
Carbon	60.79	60.75	61.31	60.77	61.57	61.62	61.70	61.36
Hydrogen	3.87	4.11	4.16	4.03	4.02	3.74	3.16	3.25
Oxygen	12.27	11.32	11.96	11.29	11.47	12.00	12.79	13.30
Nitrogen	0.86	0.93	0.90	0.91	0.92	0.90	0.85	0.88
Sulfur	0.35	0.38	0.38	0.37	0.40	0.40	0.40	0.39
Ash	5.71	6.17	6.14	6.02	6.07	6.05	6.56	6.23
Moisture	16.15	16.34	15.15	16.61	15.55	15.30	14.53	14.60
HHV , Btu/lb	10,337	10,120	10,395	10,314	10,346	10,418	10,404	10,471
(Dry Basis):								
Hg, ug/g	0.062	0.045	0.049	0.050	0.046	0.048	0.055	0.049
Cl, ug/g	104.0	97.4	125.0	110.0	101.0	244.0	241.0	166.0
SO ₂ , lb/MBtu	0.68	0.74	0.73	0.71	0.77	0.76	0.77	0.75
Hg, lb/TBtu	5.04	3.74	3.99	4.01	3.78	3.91	4.51	4.01
Hg, ug/dnm ³ (5%O ₂)	5.98	4.29	4.67	4.70	4.40	4.64	5.48	4.93

The ash composition of the coal was not measured for the second test series. The heating value, sulfur and ash contents of the August coal samples seemed consistent with the March coal samples on a dry basis. However, the average moisture content of the August coal samples was

low compared to the moisture content of the March samples: 16% versus 26%. The mercury content was also lower in the August samples on a dry basis.

It is likely that the hot air introduced into the pulverizer drove off some of the mercury from the coal into the combustion air. This could account for the apparent decrease in coal mercury (and moisture content) as compared to March. The Ontario Hydro results, discussed below, substantiate this conclusion. The effect of temperature on loss of mercury from Powder River Basin (PRB) subbituminous coals is illustrated in Figure 3. At thermal treatment temperatures above 300 F, a substantial amount of the mercury can be lost from PRB coals.

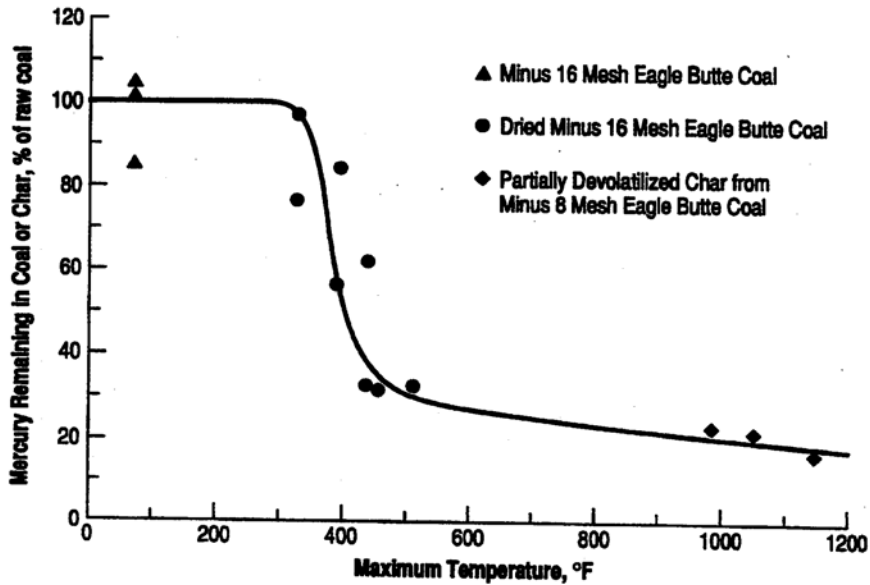


Figure 3. Mercury remaining in Eagle Butte subbituminous coal after thermal treatment. (Source: Reference 2)

Contrasting the March coal samples with the August coal samples (Figure 4), suggests that as much as 45% of the mercury in the coal was driven into the combustion gas in the pulverizers.

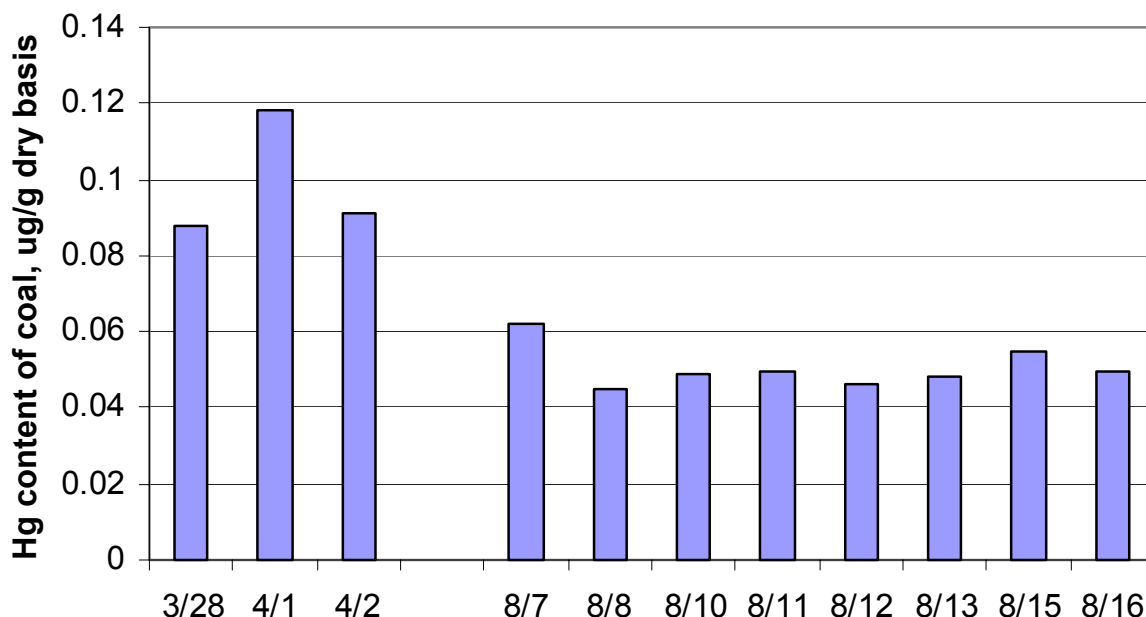


Figure 4. Coal mercury content as a function of sample date.

Ash samples were analyzed for loss on ignition (LOI), Hg and Cl, as shown in Table 4. The LOI of these samples was generally low. Since the ash was a pale tan color, the carbon content of the ash is probably even lower than the LOI indicates. In any case, the ash has a very low amount of unburned carbon. The ESP ash has 10-100 times more mercury than the economizer ash sample; this suggests that there is some adsorption of mercury by the ash that takes place between the economizer and the ESP (probably post-air preheater). However, the amount of mercury adsorbed on the ESP ash is less than 0.5% of the mercury in the coal, based on the g Hg/g of coal. Thus, the fly ash from Rockport seems unreactive toward mercury. Mercury levels in the ash from the August samples are comparable to the March/April samples.

Table 4. Composition of Ash

Description	MTI ID	Sampled	LOI, wt%	Hg, $\mu\text{g/g}$	% Hg in Ash	Cl, $\mu\text{g/g}$	%Cl in Ash
Economizer Ash	03-245	8/11/2003	0.00	0.0050	0.045%	<5	<0.3%
Economizer Ash	03-246	8/15/2003	0.00	0.0004	0.003%	<5	<0.2%
Fly Ash 3+4	03-242	8/7/2003	0.06	0.0337	0.23%	21	1.38%
Fly Ash 3+4	03-243	8/11/2003	0.30	0.0502	0.45%	21	0.67%
Fly Ash 3+4	03-244	8/15/2003	0.13	0.0549	0.47%	23	1.01%

In contrast to the March/April samples, the chlorine content of the fly ash from the ESP was higher than that from the economizer ash. The chlorine content of the fly ash was similar to that for the March/April tests. Very little of the chlorine in the coal appeared to have ended up in the

fly ash, from 0.7% to 1.4% of the total chlorine was in the fly ash in the ESP, based on g Cl/g coal. The low levels of chlorine in the economizer ash, suggest that the chlorine should be in the gas phase upstream of the air preheater.

Flue Gas Composition

The composition of the flue gas can be estimated from the coal composition. Based on the ash composition, we assume that all of the chlorine in the coal is present as HCl. NO_x averaged about 330 ppm (wet basis, 5% O₂) during the tests. Table 5 gives the estimated flue gas composition. Since it seems likely that moisture was lost in the pulverizer, the concentrations have been adjusted to a coal moisture content of 26.5%, which was the moisture content of the March coal samples.

Table 5. Flue gas composition estimated from coal composition, except as noted; coal moisture content adjusted to 26.5%.

	8/7/2003	8/8/2003	8/10/2003	8/11/2003	8/12/2003	8/13/2003	8/15/2003	8/16/2003
O ₂	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
CO ₂	12.8%	12.6%	12.6%	12.6%	12.7%	12.9%	13.3%	13.2%
H ₂ O	9.1%	9.3%	9.3%	9.2%	9.2%	8.9%	8.5%	8.6%
N ₂	73.0%	73.0%	72.9%	73.0%	73.0%	73.1%	73.1%	73.0%
SO ₂ [ppm]	278	293	295	286	307	312	324	318
HCl [ppm]	6.1	5.6	7.3	6.4	5.9	14.4	14.8	10.2
NO _x [ppm]*	330	330	330	330	330	330	330	330
Hg, ug/dnm ³ (5%O ₂)	5.94	4.26	4.64	4.67	4.37	4.60	5.44	4.89

*Estimated from previous measurements

Gas-phase halide measurements were made on August 8 and the results are given in Table 6. Three runs were made but the results of the second run were not valid. The relatively low chlorine content of the ash samples suggested that most of the chlorine would be found in the gas phase before the air preheater. The low levels of chloride measured in the gas phase were puzzling. It is possible that gaseous chlorine compounds adsorbed on the ash within the

Table 6. Results of halide measurements in gas, corrected to 5% O₂ (wet basis).

	Chloride, ppm	Cl ₂ , ppm	Fluoride, ppm	F ₂ , ppm
Run 1	0.57	<0.030	0.94	<0.000
Run 3	0.25	<0.042	0.41	<0.001
Average	0.41	<0.036	0.67	<0.001

sampling system. It would probably have been better to take the gas sample for the halide measurements at the port used for the Ontario Hydro measurements in order to determine with more certainty if the chlorine compounds were in the gas phase at the inlet to the slipstream reactor.

Three Ontario Hydro measurements were made: two on August 7 and one on August 8. The results of the Ontario Hydro measurements are given in Table 7. The Ontario Hydro probe could not be removed from the port immediately after the gas sampling was finished, so the filter was exposed to the flue gas for longer than the gas sampling time (although there was only flow through the filter during the gas sampling period). The amount of mercury on the ash is small. The total ash loading for this coal is estimated to be about 6 g/Nm³ at 5% O₂. This is an upper limit, because the full ash loading may not be drawn into the slipstream reactor. Using 6 g/Nm³ and the measured concentration of Hg in the fly ash, the maximum particulate mercury is estimated to be 0.12 µg/Nm³. This would amount to about 1% of the measured gas-phase mercury. This is similar to the measured particulate-phase mercury in the first test series. This, the amount of particulate-bound mercury will not be reported; however, it is probably only about 1% of the total mercury at the sampling location.

Table 7. Ontario Hydro measurements, corrected to 5% O₂.

Sample ID	Date of Run	Start Time	Oxidized Hg (µg/Nm ³)	Elemental Hg (µg /Nm ³)	Total Hg (µg /Nm ³)	Fly Ash Hg* (µg /g)	Filter Hg (µg)
Run 1	7-Aug-03	14:06	0.84	7.75	8.60	0.012	<0.006
Run 2	7-Aug-03	18:18	1.14	7.96	9.10	0.034	0.011
Run 3	8-Aug-03	8:21	1.22	7.62	8.83	0.016	<0.006
Average	-	-	1.07	7.77	8.84	0.0207	

* Fly ash sample taken from filter

Carbon trap samples were also taken. These were not taken at the Ontario Hydro port, but at the location where the SCEM samples were taken. Table 8 summarizes all the “inlet” mercury samples:

- Ontario Hydro samples taken near the reactor inlet
- SCEM measurements taken through the sampling system
- Carbon trap samples taken through the sampling system

The Ontario Hydro measurements made on August 7 agree well with the SCEM measurements for total mercury, although the SCEM measured lower values of elemental mercury than the Ontario Hydro. The Ontario Hydro measurements for total mercury were higher than the equivalent coal mercury. As discussed above, this may be due to vaporization of mercury from the coal in the mill. Any mercury that leaves the coal in the mill will end up in the flue gas, but it would not be measured in the solid samples at the outlet of the mill.

After August 8, the configuration of the sampling system was changed to bypass the heated switching valve and use the URS inertial separation probe. SCEM and carbon trap measurements of inlet mercury made after the change in configuration are lower than the SCEM and Ontario Hydro measurements made on August 7 and 8. This may indicate that there was some loss of mercury in the inertial separation probe.

Table 8. Inlet Mercury concentrations measured by various methods.

		SCEM Measurements				Ontario Hydro		Carbon Trap	Speciation: %Hg ⁰	
Date	Start	Hg _T	St.Dev	Hg ⁰	St.Dev	Hg _T	Hg ⁰	Hg _T	SCEM	OH
8/7	14:06					8.60	7.75			90%
8/7	14:55	7.07	<i>1.33</i>							
8/7	18:18					9.10	7.96			87%
8/7	18:40	9.83	<i>1.54</i>							
8/7	19:24	9.34	<i>2.27</i>						59%	
8/7	20:36			5.50	<i>1.44</i>					
8/8	8:21					8.83	7.62			86%
8/8	8:46	6.51	<i>0.37</i>							
8/8	10:31	4.89	<i>1.38</i>							
8/11	12:39	5.89	<i>0.43</i>							
8/11	20:03	6.33	<i>0.39</i>							
8/12	10:30							3.54		
8/12	13:27			4.19	<i>0.06</i>					
8/12	13:54	6.26	<i>0.41</i>						67%	
8/12	17:15			4.11	<i>0.32</i>					
8/12	21:04			4.32	<i>0.43</i>					
8/12	21:48	4.25	<i>0.41</i>						99%	
8/13	10:51	5.89	<i>0.32</i>						85%	
8/13	11:18			5.04	<i>0.41</i>					
8/13	14:06			4.90	<i>0.46</i>					
8/13	14:30	4.84	<i>0.39</i>						101%	
8/13	17:38			4.94	<i>0.48</i>					
8/13	18:15	4.99	<i>0.54</i>						99%	
8/15	12:07	5.05	<i>0.33</i>						65%	
8/15	12:39			3.29	<i>0.33</i>					
8/15	20:27			5.96	<i>0.78</i>					
8/15	21:24	6.29	<i>0.38</i>						95%	
8/15	22:14			6.54	<i>0.58</i>					
8/16	10:33	5.24	<i>0.25</i>							
8/16	11:57							5.22		
8/16	12:46			3.73	<i>0.58</i>					

The Ontario Hydro measurement corresponded to 88% of gaseous mercury as elemental; the Ontario Hydro measurements in March gave 81% of the gaseous mercury as elemental. The SCEM values for elemental mercury also showed a very high percentage of mercury as elemental. This is in keeping with the moderate to low chlorine levels in the coal and the high calcium in the ash.

Catalyst Activity – NO_x

The NO_x CEM was not able to be connected simultaneously with the Hg SCCEM during the March/April test series. However, for the August test series, NO_x was measured. Figures 5 and 6 show the NO_x reductions calculated from the inlet and outlet NO_x values. In Figure 5, NO_x reduction is plotted against the average of the inlet and outlet temperatures of each catalyst chamber. In Figure 6, the NO_x reduction is plotted against the space velocity. There was a clear effect of temperature on the NO_x reduction. The effect of space velocity is less clear.

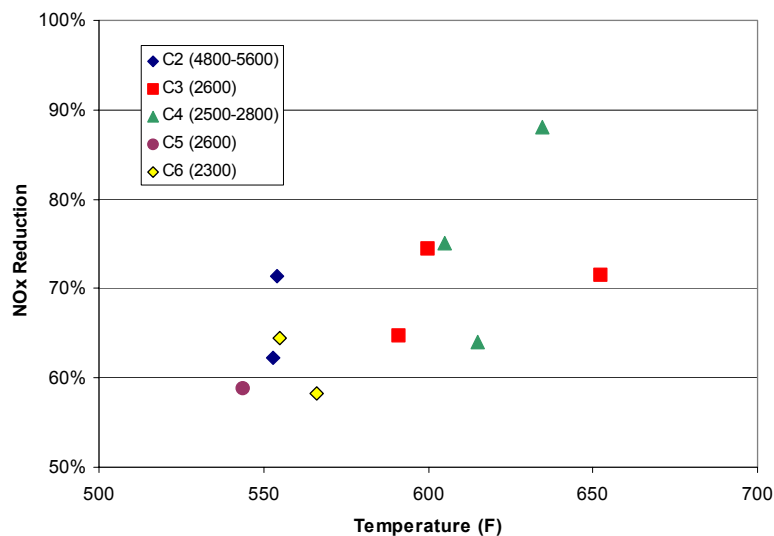


Figure 5. NO_x reduction as a function of average chamber temperature.

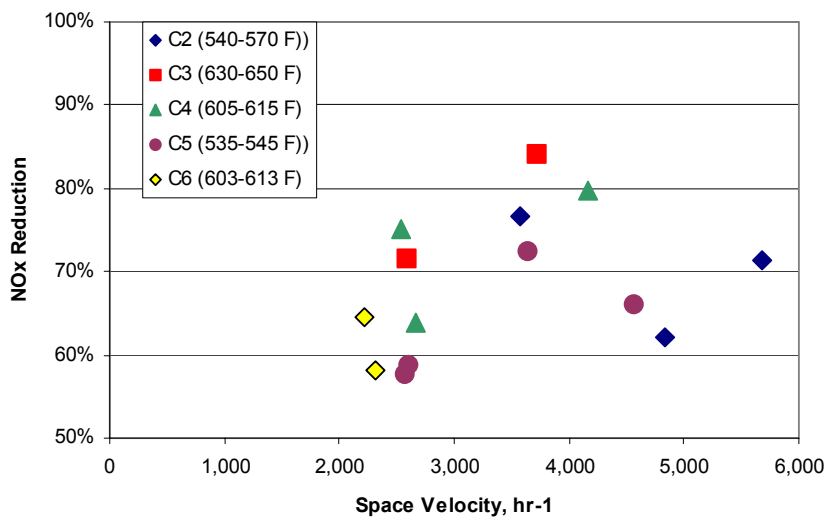


Figure 6. NO_x reduction as a function of space velocity.

Catalyst Activity – Mercury

Mercury speciation data were obtained for a wide range of space velocities, from 1,000 to 6,000 hr^{-1} . At a single space velocity, data were obtained with and without ammonia.

Control of flow through the test chambers was achieved using the eductors on each, individual chamber; the compressed air flow to the eductors was regulated by the control system, based on the desired set points. Because the flow rates needed for the mercury testing are about ten times lower than those needed for the catalyst deactivation experiments, modifications were made to the operation of the system to achieve those flow rates. The manual gate valve on the outlet of the reactor was partially closed, which restricted the flow through the reactor and increased the pressure. This allowed the eductors to control flow in the desired range. During the tests, problems were also experienced with limitation of flow rates from the catalyst chambers caused by blocked ash filters. This was manifested by high oxygen content in the gas being sampled by the SCEM, indicating that the sample pump was pulling in outside air because of the partial blockage of the ash filters.

In the March tests, the catalyst was relatively new, with only about 300 hours on flue gas at the start of the mercury testing. By August, the catalysts had about 2000 hours of exposure time (Figure 7).

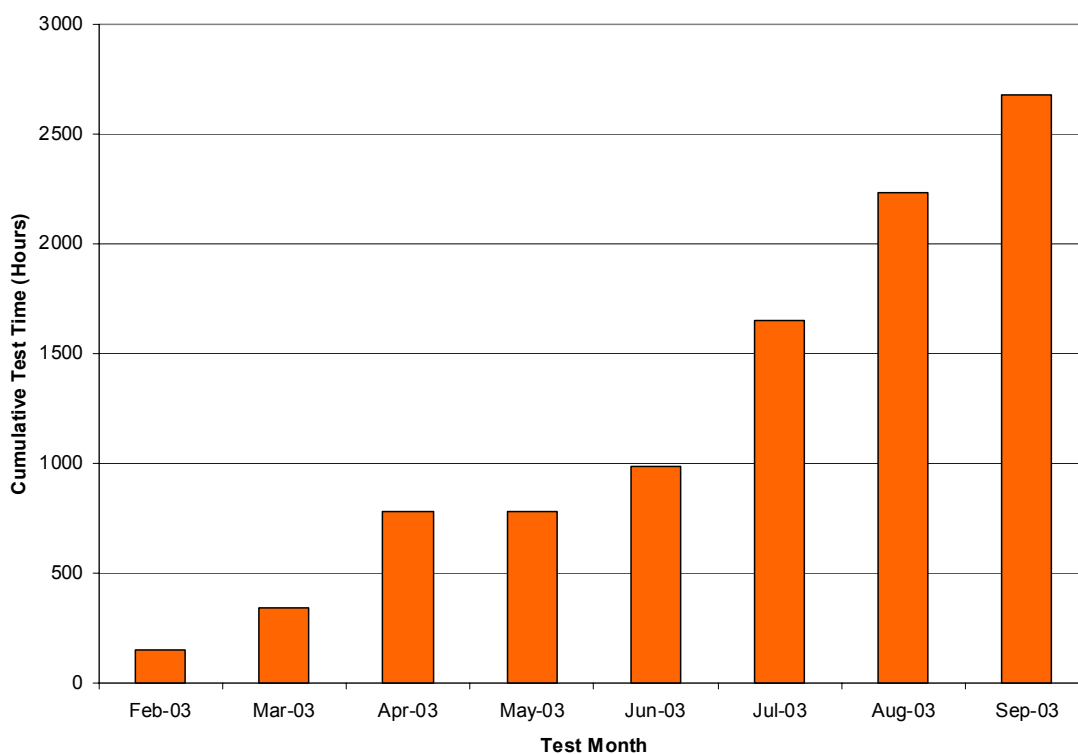


Figure 7. Cumulative exposure time to flue gas by month.

The SCEM data consist of multiple measurements (of either elemental or total mercury). Figure 8 shows one test series. In some cases, the initial points for a given sample location were not used to compute the average value. The Appendix contains the complete set of measurements (average values) for all the tests.

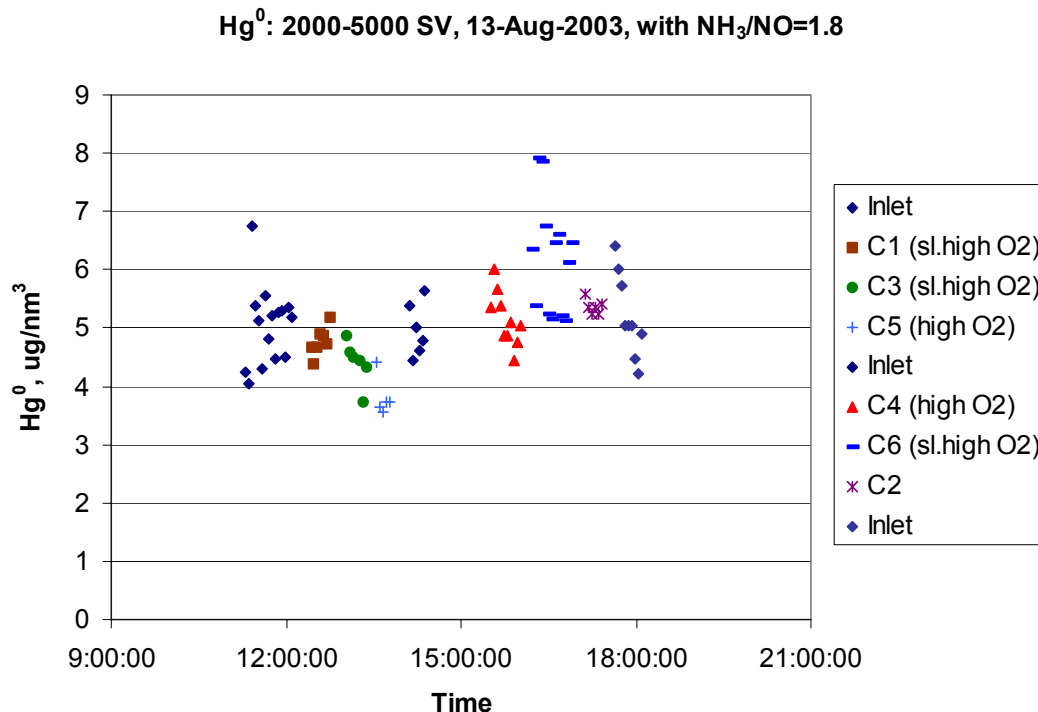


Figure 8. Mercury SCEM data ($\mu\text{g}/\text{dNm}^3$ at 5% O₂) for elemental mercury at 2000-5000 hr⁻¹ space velocity with ammonia.

From the SCEM data on mercury at the inlet and outlet of the chambers, we can calculate the loss of total mercury across the chamber and the loss of elemental mercury across the chamber. The inlet value (either Hg⁰ or total Hg_T) was measured periodically when the chamber outlet values were being measured (see Figure 8 for an example). In general, inlet value was fairly constant during a measuring period. In order to calculate the loss of elemental or total mercury across individual chambers, the inlet value was interpolated at the appropriate time.

One of the concerns from analysis of the March/April data was the apparent loss of mercury across the chambers containing active catalyst. It was hypothesized that this could be due to (a) oxidation of mercury across the catalysts and subsequent loss of some of the oxidized mercury in the sampling system or (b) adsorption of mercury by the catalysts. Changes to the sampling system were made for the August tests in order to address the first issue.

Testing was carried out on August 11 to look at the question of mercury loss. Figure 9 shows the SCEM data. If we look at the set of measurements from 18:00 on, we can see no net loss of Hg across the catalyst chambers. Figure 10 compares the computed loss of total mercury across the chambers from March/April and August. The values shown in the figure were calculated from

average values of inlet and outlet mercury. The apparent loss of total mercury observed in March/April was not seen in August.

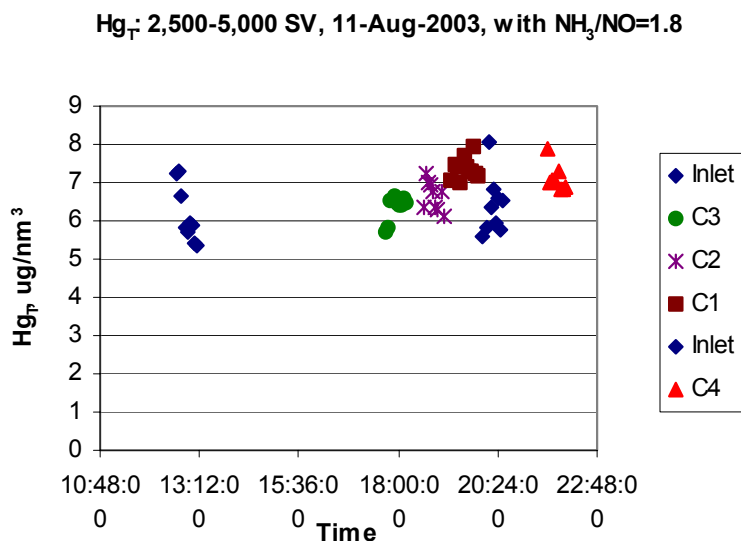


Figure 9. SCEM data from August 11: total mercury for SV of 2500-500 hr⁻¹ and NH₃/NO=1.8.

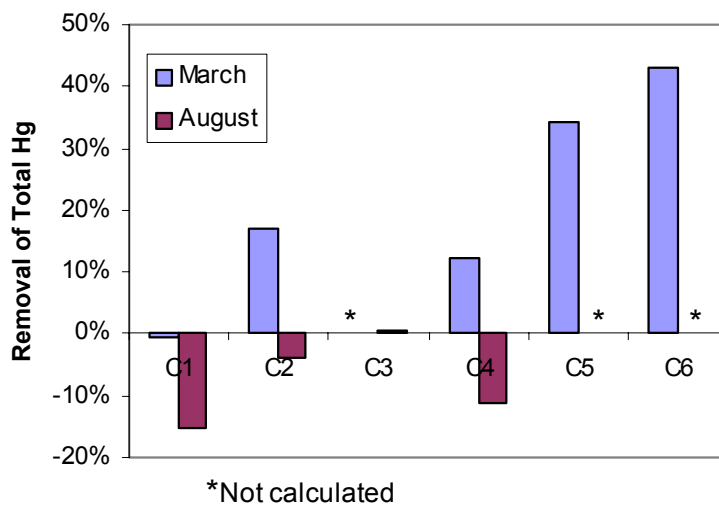
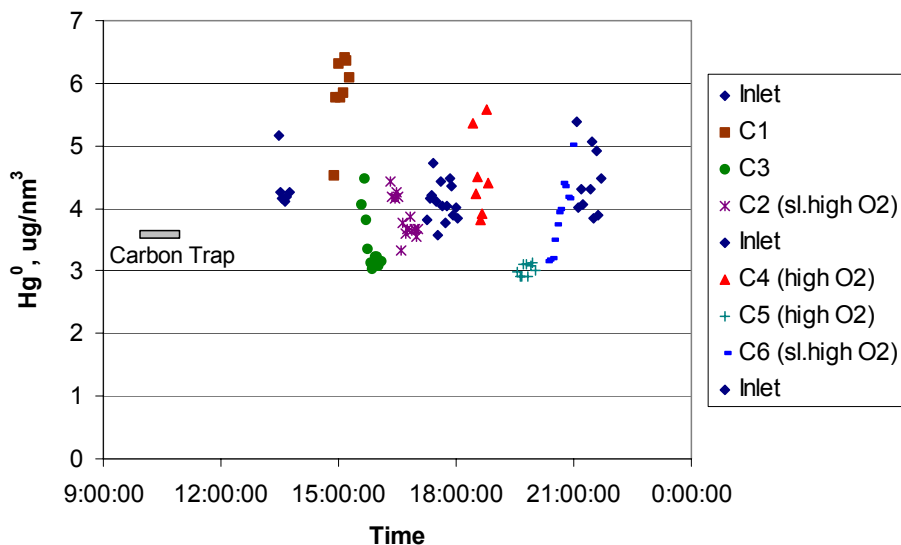


Figure 10. Change in total mercury across catalyst chambers at SV=2500-6000 hr⁻¹ and NH₃/NO ~1.8.

Measurements of elemental mercury were made on August 12 and 13 in order to examine the loss of elemental mercury (oxidation) across the catalysts. Figure 11 shows the SCEM data for

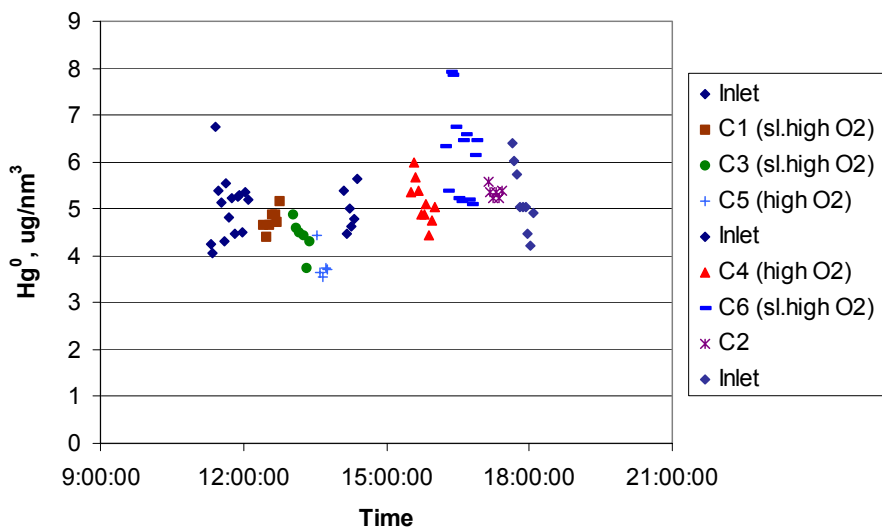
those days. The inlet concentration of elemental mercury was consistent across multiple samples. On August 12 the concentration of elemental mercury at the outlet of the blank chamber (C1) is higher than the inlet value, although not on August 13.

Hg^0 : 2,000-3,600 SV, 12-Aug-2003, with $\text{NH}_3/\text{NO}=2.1$



(a)

Hg^0 : 2000-5000 SV, 13-Aug-2003, with $\text{NH}_3/\text{NO}=1.8$



(b)

Figure 11. SCEM measurements of elemental mercury at $\text{SV}=2000\text{-}5000 \text{ hr}^{-1}$ and $\text{NH}_3/\text{NO}=1.8\text{-}2$: (a) August 12 and (b) August 13.

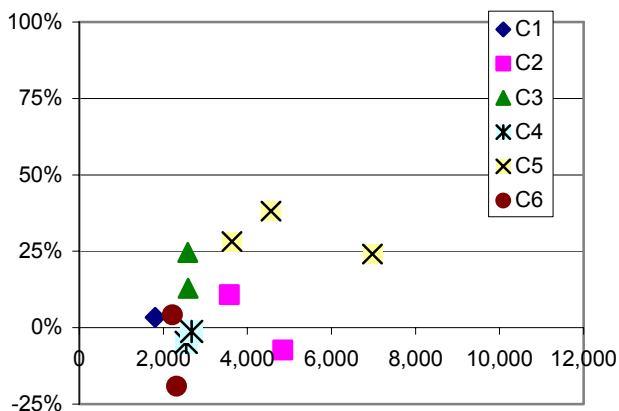
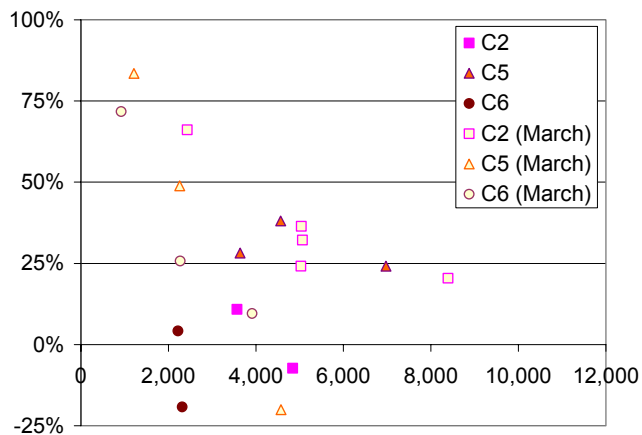


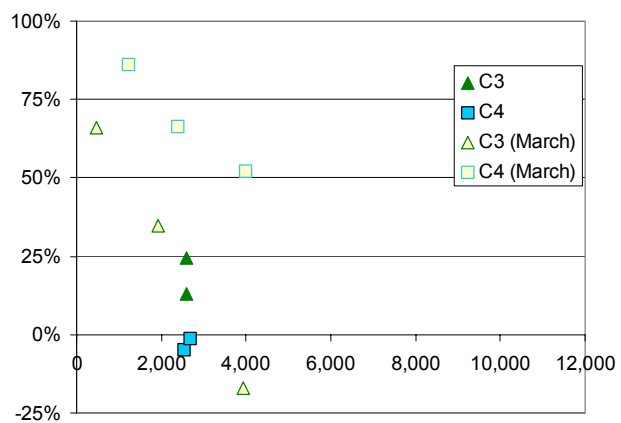
Figure 12. Mercury oxidation as a function of space velocity for $\text{NH}_3/\text{NO} = 1.8\text{-}2.1$.

catalysts (C3 and C5), oxidation during the August test series was comparable to that in the March/April series. Catalyst C2 (monolith) showed some oxidation in the August, although not as much as in March/April. Catalysts C4 and C6 showed negligible oxidation in the August test series.

The effect of space velocity on mercury oxidation is shown in Figure 12. The values shown in the figure were calculated from average values of inlet and outlet mercury. The blank monolith (C1) did not show any oxidation of elemental mercury. For the commercial catalysts, oxidation was less than 50% in general with catalysts C4 and C6 showing negligible oxidation. The range of space velocities was lower for the August test series than for the March/April test series. Figure 13 compares the March/April oxidation data to the August data. For two of the



(a)



(b)

Figure 13. Comparison of mercury oxidation from March/April and August with ammonia: (a) monolith catalysts and (b) plate catalysts.

During the March/April test series, a decrease in mercury oxidation was noted in the presence of excess ammonia. Figure 14 shows the comparison of mercury oxidation with and without ammonia from the March/April test series.

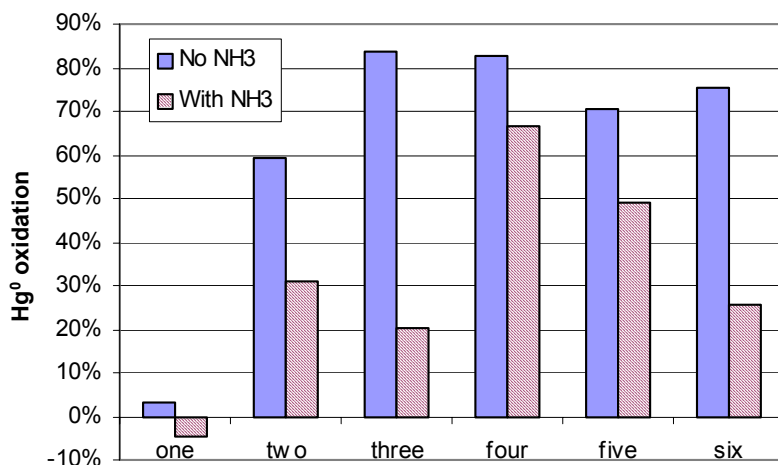


Figure 14. Mercury oxidation with ($\text{NH}_3/\text{NO}=4-5$) and without ammonia, March/April test series. $\text{SV}=2100-2400 \text{ hr}^{-1}$, with the exception of two, $\text{SV}=5100 \text{ hr}^{-1}$.

Hg^0 : 2000-5000 SV, 15-Aug-2003, with $\text{NH}_3/\text{NO}=0$

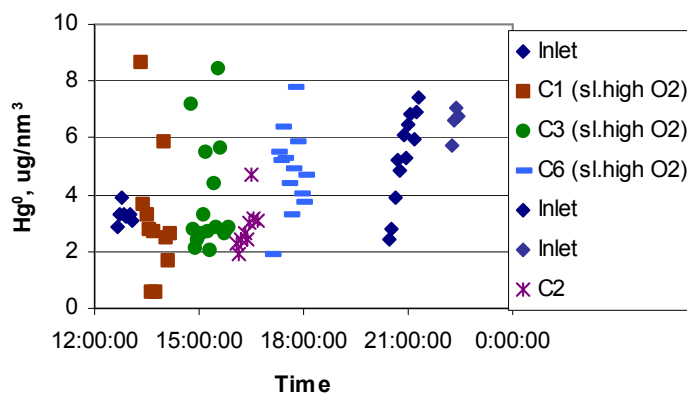


Figure 15. Elemental mercury, $\text{SV}=2000-4000 \text{ hr}^{-1}$.

In order to better understand the effects of ammonia on the catalysts, as well as transient behavior, several transient experiments were performed, in which ammonia was turned off or on while mercury and NO_x were measured at the outlet of the catalysts.

The data taken on August 15 were without ammonia. However, there was a lot of scatter in the data (Figure 15), so it is hard to interpret the data. Particularly as the inlet value of elemental mercury changed from the beginning to the end of the day.

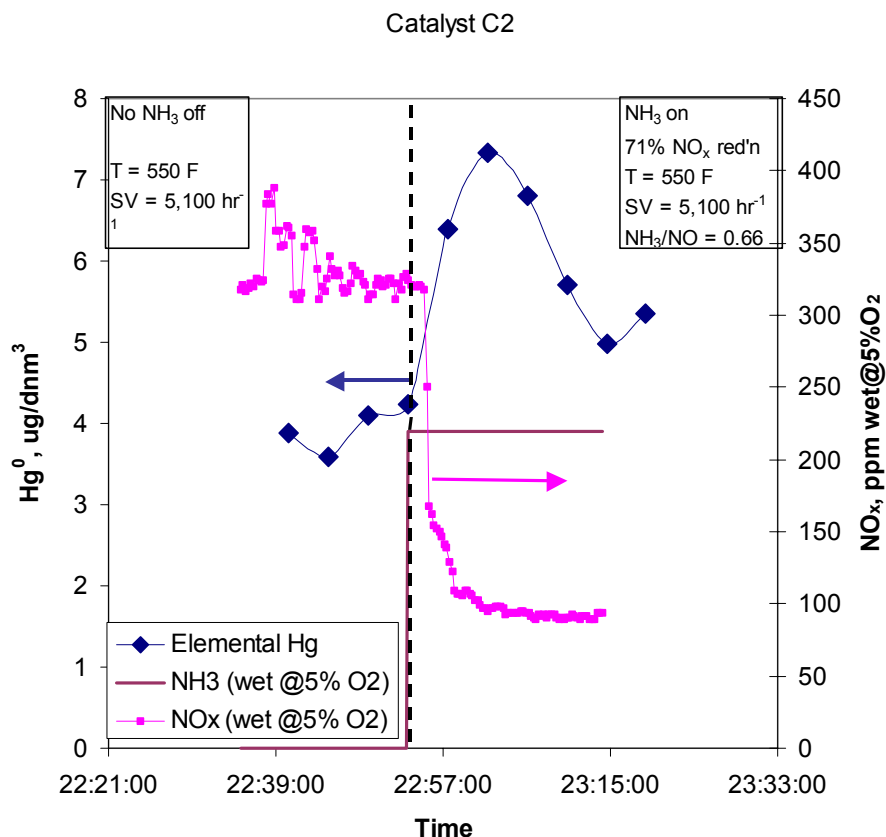


Figure 16. Elemental mercury and NO_x as a function of time for catalyst C2; T=550 F, SV=5,100 hr⁻¹.

Elemental mercury was measured continuously at the exit of catalyst C2 as the ammonia was turned on. Figure 16 shows the concentrations of elemental mercury, NO_x and ammonia as a function of time for this measurement. (The ammonia concentration was calculated from the set point of the ammonia mass flow controller and the total velocity in the slipstream reactor.) The NO_x concentration responds to the ammonia being turned on after 2-3 minutes. The time lag is related to both the residence time in the sampling line and the residence time in the ammonia delivery line. It took about ten minutes for the outlet NO_x to reach a constant value. Adding ammonia to the flue gas caused a temporary increase in elemental mercury at the exit of catalyst C2. The large increase in elemental mercury appeared to last about twenty minutes and then the elemental mercury approached some level that was higher than the pre-ammonia level. However, the measurement had to be terminated because the plant was going to reduce load. The presence of ammonia therefore increased the concentration of elemental mercury at the outlet of C2 from 4 µg/dnm³ to 5 µg/dnm³—less oxidation took place in the presence of ammonia. Furthermore, mercury seemed to *desorb* from the catalyst when ammonia was added to the flue gas, since the peak concentration of elemental mercury was greater than the measured inlet elemental mercury (6.54 µg/dnm³).

The transient experiment was repeated with catalyst C5. We also looked at the effect of changing space velocity, as shown in Figure 17. Lowering the space velocity resulted in a decrease in the average temperature in the catalyst chamber, from 600 F to 550 F. This may be why the NO_x concentration rose after the space velocity was lowered. The concentration of elemental mercury initially dropped after the space velocity was decreased, but then rose, along with the NO_x concentration. After the ammonia was turned off, the concentration of elemental mercury initially increased, and then dropped. The concentration of elemental mercury before the ammonia was turned off was about $5 \mu\text{g/dnm}^3$ and after the ammonia was turned off, it dropped to $2 \mu\text{g/dnm}^3$.

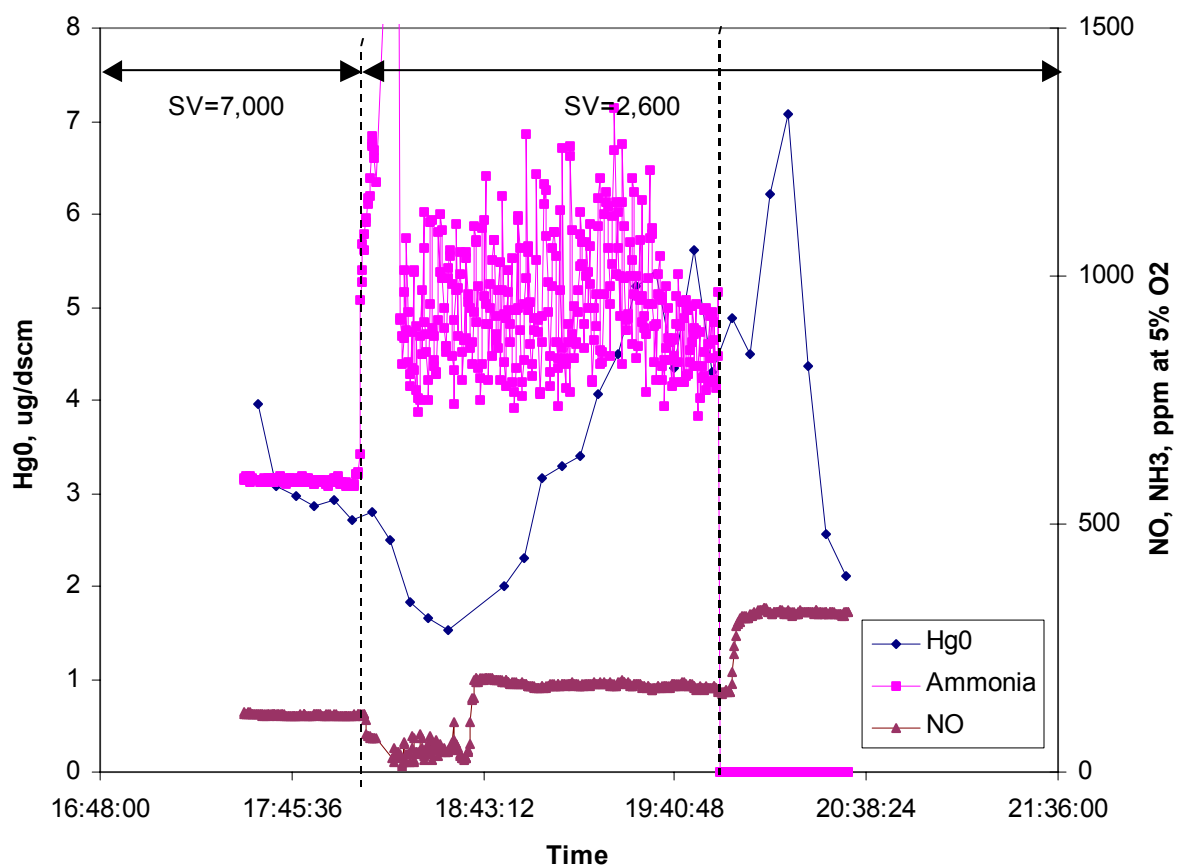


Figure 17. Elemental mercury and NO_x as a function of time for catalyst C5; $T=600 \text{ F}$, $\text{SV}=7,000 \text{ hr}^{-1}$, $\text{NH}_3/\text{NO}=1.8$ or $T=540 \text{ F}$, $\text{SV}=2,600 \text{ hr}^{-1}$, $\text{NH}_3/\text{NO}=2.8$.

The sampling line for catalyst C5 became blocked, so it was not possible to continue sampling C5. In order to observe the behavior when ammonia was turned on, the exit from catalyst C3 was sampled. Figure 18 shows that when the ammonia was turned on again, the concentration of NO_x returned quickly to the previous level (see Figure 17). The concentration of elemental mercury rose from about $1.8 \mu\text{g}/\text{dm}^3$ (without ammonia) and peaked after about 45 minutes. The peak concentration of $10.6 \mu\text{g}/\text{dm}^3$ was far in excess of the observed inlet levels of elemental mercury. Once again, elemental mercury appears to have desorbed from the catalyst when ammonia was turned on. Unfortunately, there was not sufficient time at full load to continue the mercury measurements.

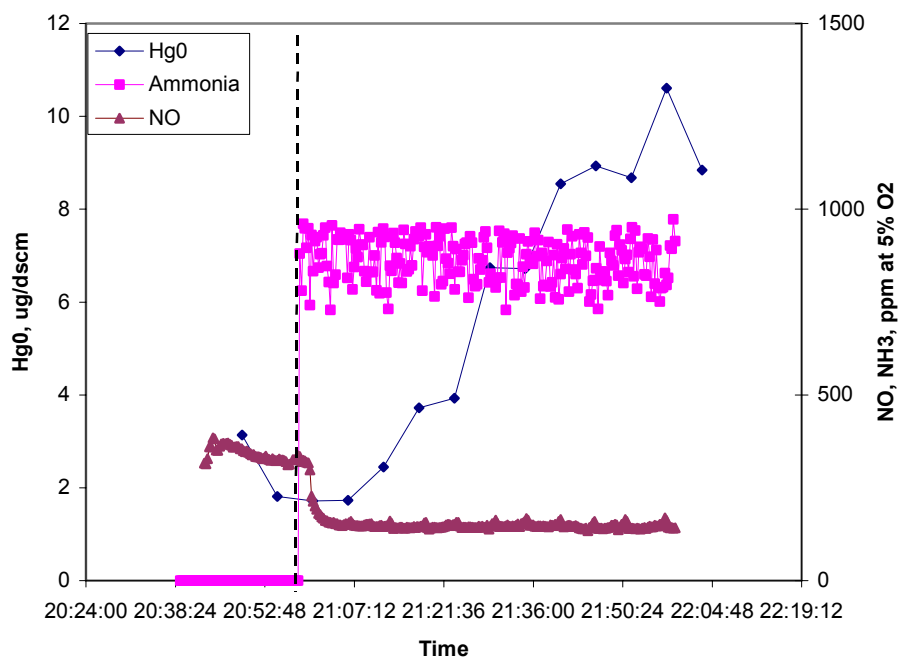


Figure 18. Elemental mercury and NO_x as a function of time for catalyst C3; $T=574 \text{ F}$, $\text{SV}=1.110 \text{ hr}^{-1}$, $\text{NH}_3/\text{NO}=2.5$

Conclusions

Good progress has been made on several fronts during the last three months. In particular:

A second set of mercury measurements was made in August when the catalysts had been exposed to flue gas for about 2,000 hours. These were compared to the March/April test series when the catalyst had only been exposed to flue gas for about 300 hours.

The coal composition for the August test series was similar to that from the March/April test series. However, the August coal samples were taken from the mill outlets, not the inlets, as were the March/April samples. The August samples had considerably less moisture and less mercury. The gas-phase mercury concentration, according to Ontario Hydro measurements, was about the same in August as in March/April, suggesting that the temperature in the mills drove some of the coal mercury into the combustion air. Thus, sampling after the mills will not produce an accurate coal mercury concentration.

There was good agreement between the Ontario Hydro measurements and the SCEM measurements. Carbon trap measurements of total mercury agreed fairly well with the SCEM. There did appear to be some loss of mercury in the sampling system toward the end of the sampling campaign. However, mercury measured at the outlet of the blank monolith generally agreed well with mercury measured at the inlet to the catalyst chambers. This suggests that relative comparisons of inlet and outlet mercury are valid for these data.

Relatively little mercury or chlorine was observed in the ash collected from the economizer and the ESP hoppers. The mercury and chlorine concentrations were similar to those from the March/April tests. Gas-phase halide species were measured using an impinger method. These showed that only about 10% of the chlorine in the coal was present in the gas phase.

NO_x reductions across the catalysts ranged from 60% to 88% and were strongly dependent on the temperature in the catalyst chamber.

Loss of total mercury across the commercial catalysts was not observed, as it had been in the March/April test series. It is not clear whether this was due to aging of the catalyst or to changes in the sampling system made between March/April and August.

In the presence of ammonia, the blank monolith showed no oxidation. Catalysts C3 (plate) and C5 (monolith) showed the most oxidation; the oxidation was comparable to that in the March/April series. These catalysts showed no loss of activity toward elemental mercury after 2000 hours of exposure to flue gas. The other commercial catalysts exhibited less oxidation in the August tests relative to the March/April tests. Catalyst C2 (monolith) showed some oxidation in the August tests, although not as much as in the March/April tests. Catalysts C4 and C6 showed negligible oxidation in the August test series.

Oxidation of mercury increased without ammonia present. Transient experiments showed that when ammonia was turned on, mercury appeared to desorb from the catalyst, suggesting displacement of adsorbed mercury by the ammonia.

During the next quarter, data analysis of the Rockport field testing will be concluded. Analysis measurements of mercury oxidation of full-scale catalysts will be started.

References

1. Richardson, C., Machalek, T., Miller, S. "Effect of NO_x Control Processes on Mercury Speciation in Utility Flue Gas." Presented at the at the Air Quality III Meeting, Washington, D.C., September 10-13, 2002.
2. Merriam, N. W., Grimes, R. W., Tweed, R. E., "Process for low mercury coal," United States Patent 5,403,365, April 4, 1995.

Appendix:
Mercury Measurements from Semi-Continuous Monitor

Table A-1. SCEM Data for August 2003

				Average SCEM					Temperatures, F				Gas Composition				
Date	Start	End	Measurement	O2, % dry	Hg (@5% O2) ug/dscm	St.Dev of Hg	Total reactor flow, scfm	Average SV in chamber, 1/hr (32 F)	Duct	Before catalysts	Cabinet (outside catalysts)	Average catalyst chamber	NOx (ppm dry)	O2 (% dry)	NOx (5%O2, wet)	NH3 (5% O2, wet)	NH3/NO
8/7/03	14:55:25	15:24:52	Inlet Tot	15.07	7.07	1.33	85.48		745	655	511		--	--	--	--	--
8/7/03	15:30:46	15:45:29	1 Tot	9.90	6.82	1.14	85.49		744	663	521	590	--	--	--	--	--
8/7/03	18:40:55	19:07:22	Inlet Tot	9.35	9.83	1.54	96.18		735	650	498		--	--	--	--	--
8/7/03	19:24:10	19:57:47	Inlet Tot	6.67	9.34	2.27	95.90		734	659	508		--	--	--	--	--
8/7/03	20:36:34	21:37:04	Inlet Elem	4.61	5.50	1.44	97.56		734	668	520		--	--	--	--	--
8/8/03	8:46:19	9:30:29	Inlet Tot	5.56	6.51	0.37	98.48		739	638	501		--	--	--	--	--
8/8/03	10:31:04	11:07:28	Inlet Tot	4.99	4.89	1.38	99.18		739	658	527		--	--	--	--	--
8/11/03	12:39:25	13:08:18	Inlet Tot	4.76	5.89	0.43	91.05		742	669	535		362	5.10	335	182	0.54
8/11/03	15:21:38	16:26:38	3 Tot	11.87	4.47	0.37	96.63	2,587	745	619	518	599	0	21.00		606	1.81
8/11/03	16:44:42	17:13:35	1 Tot	16.47	3.72	0.60	96.14	2,958	744	617	518	555	0	21.00		609	1.82
8/11/03	17:42:29	18:11:22	3 Tot	7.17	6.51	0.08	96.34	2,599	749	619	523	600	78	7.17	83	607	1.81
8/11/03	18:36:39	19:05:32	2 Tot	6.84	6.60	0.34	95.40	5,687	745	617	523	554	92	6.51	94	614	1.83
8/11/03	19:16:22	19:56:06	1 Tot	7.82	7.36	0.27	95.14	2,745	744	617	521	555	287	7.19	307	615	1.84
8/11/03	20:03:19	20:32:12	Inlet Tot	4.40	6.33	0.39	93.10		747	658	528		326	6.06	334	629	1.88
8/11/03	21:36:34	22:01:51	4 Tot	8.12	6.99	0.17	95.53	4,169	742	617	520	603	55	8.72	66	613	1.83
8/12/03	13:27:50	13:44:14	Inlet Elem	4.53	4.19	0.06	83.89		751	673	553		383	4.80	347	697	2.01
8/12/03	13:54:04	14:36:41	Inlet Tot	5.03	6.26	0.41	88.11		751	676	553		384	3.51	322	663	2.06
8/12/03	14:53:05	15:16:01	1 Elem	5.62	6.09	0.28	95.02	1,406	754	678	555	602	366	4.85	333	627	1.88
8/12/03	15:35:41	16:05:11	3 Elem	5.11	3.17	0.10	103.03	2,583	752	678	552	652	103	4.97	94	576	1.74
8/12/03	16:18:50	17:02:32	2 Elem	6.14	3.75	0.27	82.28	3,568	747	644	547	570	82	5.40	77	716	2.16
8/12/03	17:15:59	18:03:02	Inlet Elem	4.80	4.11	0.32	80.49		745	664	538		392	3.85	335	732	2.18
8/12/03	18:26:34	18:50:06	4 Elem	10.19	4.41	0.63	80.80	2,541	743	617	530	605	52	11.70	83	713	2.15
8/12/03	19:33:48	20:00:42	5 Elem	10.53	3.02	0.09	80.99	3,635	743	607	517	543	49	13.07	92	712	2.15
8/12/03	20:17:30	20:54:29	6 Elem	7.49	4.03	0.31	78.71	2,219	740	603	514	555	116	6.52	118	733	2.21
8/12/03	21:04:34	21:41:32	Inlet Elem	4.52	4.32	0.43	81.88		741	651	526		392	3.72	333	705	2.12
8/12/03	21:48:15	22:15:09	Inlet Tot	4.53	4.25	0.41	82.77		740	660	539		382	3.53	321	697	2.17
8/13/03	10:51:30	11:08:19	Inlet Total	4.63	5.89	0.32	89.12		736	669	524		368	3.63	311	418	1.35
8/13/03	11:18:24	12:05:28	Inlet Elem	4.71	5.04	0.41	89.95		733	666	525		367	3.60	310	520	1.68

				Average SCEM					Temperatures, F				Gas Composition				
Date	Start	End	Measurement	O2, % dry	Hg (@5% O2) ug/dscm	St.Dev of Hg	Total reactor flow, scfm	Average SV in chamber, 1/hr (32 F)	Duct	Before catalysts	Cabinet (outside catalysts)	Average catalyst chamber	NOx (ppm dry)	O2 (% dry)	NOx (5%O2, wet)	NH3 (5% O2, wet)	NH3/NO
8/13/03	12:25:38	12:45:48	1 Elem	7.83	4.79	0.26	89.70	1,803	731	617	526	553	297	6.90	309	569	1.78
8/13/03	13:02:36	13:22:46	3 Elem	7.78	4.32	0.34	91.54	2,587	730	610	516	591	109	6.78	113	555	1.74
8/13/03	13:32:52	13:46:19	5 Elem	10.64	3.07	0.08	90.62	4,564	730	608	512	547	59	13.00	108	561	1.76
8/13/03	14:06:29	14:23:17	Inlet Elem	4.85	4.90	0.46	88.85		731	650	522		366	4.75	331	572	1.73
8/13/03	14:30:00	15:17:04	Inlet Totals	5.15	4.84	0.39	89.05		733	659	534		371	3.59	313	570	1.82
8/13/03	15:30:31	16:00:46	4 Elem	13.02	5.02	0.38	92.20	2,669	736	626	540	615	61	13.24	115	551	1.73
8/13/03	16:14:13	16:54:33	6 Elem	7.56	5.91	0.71	89.57	2,314	735	613	530	566	132	6.49	133	567	1.78
8/13/03	17:08:00	17:24:48	2 Elem	7.07	5.32	0.07	90.33	4,841	737	611	528	553	120	6.33	121	562	1.76
8/13/03	17:38:15	18:05:08	Inlet Elem	4.72	4.94	0.48	85.38		733	652	537		370	4.59	331	595	1.80
8/13/03	18:15:13	18:35:23	Inlet Totals	4.74	4.99	0.54	85.39		737	661	549		377	3.59	318	595	1.87
8/15/03	12:07:11	12:31:20	Inlet Totals	4.37	5.05	0.33	80.64		727	644	528		371	6.38	373	0	0.00
8/15/03	12:39:32	13:03:42	Inlet Elem	4.38	3.29	0.33	81.11		726	650	539		390	5.93	380	0	0.00
8/15/03	13:20:26	13:44:36	1 Elem	5.56	3.19	2.73	77.50	455	728	654	546	581	313	10.34	431	0	0.00
8/15/03	13:57:14	14:10:49	1 Elem	6.18	3.18	1.86	76.46	110	728	656	547	582	354	8.32	410	0	0.00
8/15/03	14:44:10	15:50:51	3 Elem	5.65	3.79	1.92	75.52	2,584	730	660	551	636	332	9.60	428	0	0.00
8/15/03	16:04:11	16:39:44	2 Elem	4.28	2.85	0.81	75.57	3,976	728	660	553	586	362	8.42	424	0	0.00
8/15/03	17:06:25	18:04:11	6 Elem	6.36	6.12	4.90	77.67	2,251	729	618	540	576	215	14.37	476	0	0.00
8/15/03	20:27:07	21:19:39	Inlet Elem	4.62	5.96	0.78	77.57		728	648	529		373	4.96	345	0	0.00
8/15/03	21:24:25	21:48:18	Inlet Totals	4.48	6.29	0.38	78.81		730	655	536		376	4.26	330	0	0.00
8/15/03	22:14:33	22:27:22	Inlet Elem	5.35	6.54	0.58	78.79		728	656	538		368	4.03	319	0	0.00
8/15/03	22:35:56	22:53:02	2 Elem (no NH3)	6.96	4.44	1.12	80.37	5,101	730	626	535	554		6.31	332	0	0.00
8/15/03	22:57:19	23:14:25	2 Elem(NH3)	7.24	6.04	1.00	79.84	5,125	729	612	525	543		6.12	97	219	0.66
8/16/03	10:33:53	11:41:48	Inlet Totals Inlet	4.34	5.24	0.25	162.47		731	673	593		355	7.35	309	408	1.32
8/16/03	12:46:03	13:26:49	Elementals	4.45	3.73	0.58	178.86		727	683	613		351	7.62	389	503	1.29
8/16/03	16:33:51	17:08:37	C#3 elemental	11.13	1.23	0.41	152.78	3,715	735	645	578	631	38	10.94	55	589	1.69
8/16/03	17:31:04	18:10:55	C#5 elemental	5.88	2.83	0.19	143.95	6,973	736	645	579	604	110	6.61	112	656	1.88
8/16/03	18:16:37	19:53:27	C#5 ele, SV=3k	6.71	4.89	0.53	43.91	2,593	737	608	553	544	135	7.75	144	960	2.75

				Average SCEM					Temperatures, F				Gas Composition				
Date	Start	End	Measurement	O ₂ , % dry	Hg (@5% O ₂) ug/dscm	St.Dev of Hg	Total reactor flow, scfm	Average SV in chamber, 1/hr (32 F)	Duct	Before catalysts	Cabinet (outside catalysts)	Average catalyst chamber	NO _x (ppm dry)	O ₂ (%) (dry)	NO _x (5%O ₂ , wet)	NH ₃ (5% O ₂ , wet)	NH ₃ /NO
8/16/03	19:59:08	20:32:56	C#5 ele, NH3 off	6.63	4.47	1.96	47.05	2,607	737	601	542	540	312	6.67	320	0	0.00
8/16/03	20:39:13	20:56:46	C#3 ele, NH3 off	6.65	3.59	1.89	47.05	1,112	737	601	542	574	284	8.64	344	861	0.00
8/16/03	21:01:47	21:58:44	C#3 ele, NH3 on	6.65	9.12	0.84	47.31	1,115	737	599	539	573	145	6.57	148	861	2.47

Table A-2. SCEM Data for March 2003.

Date	Start Time	End Time	Channel	Measure- ment	Hg @5% O ₂	Std. Dev	Hg ⁰ oxidation	Total flow, scfm	SV (32 F), hr ⁻¹	Tduct, F	TbfrC, F	Tcab, F	Tcat- avg, F	NO _x (5%O ₂ , wet)	NH ₃ , ppm	NH ₃ /NO
3/28/2003	0:41:23	0:41:39	inlet					143.88			651	664		217	0	0.00
3/28/2003	4:21:28	4:23:21	inlet					151			648	659		314	610	1.94
3/28/2003	4:39:08	4:41:00	four					150	2932		658	661	653	49	613	
3/28/2003	4:49:50	4:51:26	inlet					151			662	666		323	631	1.96
3/28/2003	4:58:24	5:00:16	five					149	7036		664	669		43	632	
3/28/2003	5:09:06	5:10:42	inlet					151			666	672	650	327	622	1.90
3/28/2003	5:17:39	5:19:32	six					151	7172		665	674	649	385	616	1.60
3/28/2003	5:29:10	6:54:21	inlet					151			664	674		310	525	1.70
3/28/2003	9:17:50	9:47:49	inlet	Inlet-Elem	5.68	0.19		94			652	657			1417	4.45
3/28/2003	9:48:05	10:18:03	one	1-Elem	5.77	0.34	-3.90%	95	2538		657	659	622		1404	4.41
3/28/2003	10:18:20	10:48:18	two	2-Elem	4.21	0.16	24.17%	95	5030		660	661	629		1399	4.39
3/28/2003	10:48:34	11:18:32	three					94	2428		660	662	650		1413	4.44
3/28/2003	11:20:57	11:50:55	inlet	Inlet-Elem	5.53	0.20		94			655	660			1411	4.43
3/28/2003	11:51:11	12:21:10	four					94	2400		652	658	645		1421	4.46
3/28/2003	12:21:26	12:51:25	five					94	4122		654	657	626		1418	4.45
3/28/2003	12:51:41	13:21:40	six					94	3395		654	658	626		1424	4.47
3/28/2003	13:23:48	13:53:15	inlet	Inlet-Elem	5.62	0.30		93			655	658			1425	4.47
3/28/2003				Inlet-Elem	5.10	0.24										
3/28/2003	14:39:34	**	two					139.64	6,675		659	655	628		0	0.00
3/28/2003	14:41:58	**	one					219	10677		663	656	635		0	0.00
3/28/2003	14:42:14	**	three					219	4060		664	656	651		0	0.00
3/28/2003	14:42:30	**	five					221	10047		665	656	643		0	0.00
3/28/2003	14:42:46	**	six					223	10770		666	656	643		0	0.00
3/28/2003	16:18:05	17:03:03	two	2-Elem	3.77	0.26	32.17%	92	5064		654	659	625		1370	4.30
3/28/2003	17:05:28	17:20:11	inlet	Inlet-Tot	7.63	0.23		85			646	654			1548	4.86
3/28/2003	17:20:43	17:35:26	one	1-Tot	7.68	0.36		85	2097		647	654	620		1545	4.85
3/28/2003	17:35:43	17:50:26	three					85	2409		647	654	638		1562	4.90
3/28/2003	17:50:58	18:05:41	four	4-Tot	6.69	0.37		82	2395		647	654	640		1618	5.08
3/31/2003	12:10:29	12:11:17	one					86	2125	721	650	656	614		0	0.00

Date	Start Time	End Time	Channel	Measure- ment	Hg @5% O ₂	Std. Dev	Hg ⁰ oxidation	Total flow, scfm	SV (32 F), hr ⁻¹	Tduct, F	TbfrC, F	Tcab, F	Tcat- avg, F	NO _x (5%O ₂ , wet)	NH ₃ , ppm	NH ₃ /NO
3/31/2003	12:11:49	12:14:03	two	Inlet	-			85	5032	721	648	655	623		0	0.00
3/31/2003	12:37:05	12:57:10	inlet	elem	5.16	0.51		75		719	637	655			1760	5.53
3/31/2003	12:57:26	13:17:14	one	1-Elem	8.03	0.16	-5%	80	2124	718	631	657	598		1652	5.19
3/31/2003	13:17:30	13:37:18	two	2-Elem	4.85	0.25	36%	78	5037	721	629	658	609		1690	5.31
3/31/2003	13:37:35	13:57:39	three	3-Elem	4.99	1.02	35%	77	1927	720	629	661	620		1719	5.41
3/31/2003	13:59:47	14:19:52	inlet	elem	5.19	0.54		79		719	628	660			1668	5.24
3/31/2003	14:20:08	14:39:56	four	4-Elem	2.56	0.08	66%	79	2400	719	627	655	627		1673	5.26
3/31/2003	14:40:12	15:00:00	five	5-Elem	3.90	1.20	49%	79	2259	721	626	655	590		1669	5.25
3/31/2003	15:00:16	15:20:21	six	6-Elem	5.67	1.00	26%	79	2270	718	626	655	610		1670	5.25
3/31/2003	15:22:29	15:42:33	inlet	elem	4.64	0.26		80		716	624	659			1649	5.19
3/31/2003	16:01:01	16:20:49	inlet	Inlet-Tot	7.33	0.15		85		720	635	652			0	0.00
3/31/2003	16:21:05	16:40:54	one	1-Tot	7.37	0.42		83	2226	719	632	654	599		0	0.00
3/31/2003	16:41:10	17:00:58	two	2-Tot	2.92	0.38		84	5029	719	631	655	608		0	0.00
3/31/2003	17:01:30	17:21:19	three	3-Tot	4.63	0.50		82	2444	722	630	655	621		0	0.00
3/31/2003	17:23:27	17:43:32	inlet	Inlet-Tot	6.18	0.53		80		719	630	654			0	0.00
3/31/2003	17:43:48	18:03:36	four	4-Tot	5.40	0.28		82	2403	717	628	654	626		0	0.00
3/31/2003	18:03:52	18:23:41	five	5-Tot	3.30	0.43		83	2305	718	629	654	595		0	0.00
3/31/2003	18:23:57	18:43:49	six	6-Tot	5.49	1.05		81	2092	720	630	653	613		0	0.00
3/31/2003	18:46:13	19:06:01	inlet	Inlet-Tot	7.48	0.27		163		722	639	654			0	0.00
4/1/2003	8:37:48	8:57:37	inlet	Inlet-Tot	7.48	0.68		75		716	638	655			1757	5.49
4/1/2003	8:57:53	9:17:41	one	1-Tot	9.50	0.22		71	693	715	631	657	600		1870	5.84
4/1/2003	9:17:57	9:38:01	two	2-Tot	6.07	0.33		69	4991	714	627	657	609		1914	5.98
4/1/2003	9:38:17	9:58:06	three					71	1832		625	657	619		1868	5.84
4/1/2003	10:00:31	10:20:19	inlet	Inlet-Tot	8.02	0.28		69		718	623	656			1917	5.99
4/1/2003	10:20:35	10:40:24	four	4-Tot	4.90	0.49		67	2399	718	622	656	624		1981	6.19
4/1/2003	10:40:40	11:00:28	five	5-Tot	5.26	0.82		67	2265	717	621	656	597		1980	6.19
4/1/2003	11:00:44	11:20:49	six	6-Tot	4.56	0.53		67	2305	718	621	656	610		1961	6.13
4/1/2003	11:22:57	11:39:16	inlet	Inlet-Tot	7.97	0.11		106		715	623	657			1013	3.17

Date	Start Time	End Time	Channel	Measure- ment	Hg @5% O ₂	Std. Dev	Hg ⁰ oxidation	Total flow, scfm	SV (32 F), hr ⁻¹	Tduct, F	TbfrC, F	Tcab, F	Tcat- avg, F	NO _x (5%O ₂ , wet)	NH ₃ , ppm	NH ₃ /NO
4/1/2003	14:58:27	15:18:15	inlet	Inlet-Elem	5.52	0.21		35		720	637	661			795	2.49
4/1/2003	15:18:31	15:38:20	one					28	0		615	660	420		928	2.90
4/1/2003	15:38:52	15:58:40	two	2-Elem	1.69	0.21	66%	30	2431	720	608	665	589		883	2.76
4/1/2003	15:58:56	16:18:45	three	3-Elem	1.70	0.25	66%	32	463	722	604	661	596		834	2.61
4/1/2003	16:21:09	16:40:58	inlet	Inlet-Elem	4.16	0.46		28		718	599	661			937	2.93
4/1/2003	16:41:14	17:01:02	four	4-Elem	0.69	0.19	86%	33	1218	720	596	657	600		805	2.52
4/1/2003	17:01:18	17:21:22	five	5-Elem	0.82	0.21	84%	35	1210	722	596	649	574		746	2.33
4/1/2003	17:21:38	17:41:26	six	6-Elem	1.41	0.42	72%	33	921	721	597	649	592		803	2.51
4/1/2003	17:43:51	18:03:39	inlet	Inlet-Elem	4.76	0.85		32		717	595	652			826	2.58
4/1/2003	18:03:55	18:23:44	two	2-Tot	6.94	0.77		38	2482	719	594	656	581		695	2.17
4/1/2003	18:24:00	18:43:48	four	4-Tot	6.82	0.50		35	1134	718	594	659	601		743	2.32
4/1/2003	18:46:13	19:06:01	inlet	Inlet-Tot	8.35	0.35		135		714	608	659			415	1.30
4/1/2003	9:09:56	9:29:45	inlet	Inlet-Elem	6.55	0.98		83		723	652	670			0	0.00
4/1/2003	9:30:01	9:49:50	one	1-Elem	6.31	0.51	3.04%	81	2064	724	646	663	619		0	0.00
4/1/2003	9:50:06	10:10:12	two	2-Elem	2.57	0.75	59.07%	82	5051	725	643	661	618		0	0.00
4/1/2003	10:10:28	10:30:17	three	3-Elem	0.99	0.28	83.78%	82	2439	723	640	661	631		0	0.00
4/1/2003	10:32:42	10:52:31	inlet	Inlet-Elem	5.98	0.76	0.28%	81		723	638	660			0	0.00
4/1/2003	10:52:47	11:12:37	four	4-Elem	1.03	0.59	82.46%	82	2353	724	638	659	633		0	0.00
4/1/2003	11:12:53	11:32:42	five	5-Elem	1.72	0.99	70.27%	81	2132	726	637	661	610		0	0.00
4/1/2003	11:32:58	11:53:03	six	6-Elem	1.41	0.21	75.28%	83	2219	725	637	662	616		0	0.00
4/1/2003	11:55:12	12:15:03	inlet	Inlet-Elem	5.59	0.60		83		726	638	660			0	0.00
4/1/2003	12:41:03	13:00:52	inlet	Inlet-Elem	4.77	0.47		139		723	656	666			1274	3.98
4/1/2003	13:01:24	13:21:14	one	1-Elem	4.95	0.24	-2.79%	139	3580	725	656	666	630		1272	3.98
4/1/2003	13:21:30	13:41:20	two	2-Elem	3.84	0.25	20.42%	140	8389	727	657	666	637		1261	3.94
4/1/2003	13:41:36	14:01:25	three	3-Elem	5.63	0.23	-16.91%	137	3921	727	659	667	653		1292	4.04
4/1/2003	14:01:41	14:21:47	four	4-Elem	2.31	0.24	52.04%	138	3992	725	658	667	656		1283	4.01
4/1/2003	14:22:03	14:41:52	five	5--Elem	5.79	0.25	-20.02%	137	4571	727	659	667	633		1291	4.03
4/1/2003	14:42:09	15:01:58	six	6-Elem	4.36	0.41	9.54%	138	3915	726	659	668	637		1284	4.01
4/1/2003	15:04:23	15:24:11	inlet	Inlet-Elem	4.86	0.54		137		724	658	668			1289	4.03
4/1/2003	15:26:36	15:46:27	inlet	Inlet-Total	6.47	0.35		138		726	659	668			1284	4.01